GRISPE PLUS
VALORISATION OF KNOWLEDGE
FOR SPECIFIC PROFILED STEEL SHEETS

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D3.1 STEEL DECK WITH EMBOSSMENTS

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PART 1: DESIGN MANUAL FOR STEEL DECKS WITH EMBOSSMENTS

SUMMARY

The purpose of this design manual is to present a new method of design by calculation for steel decking with embossments, as developed in the European project GRISPE PLUS.

The manual is based on the Eurocode principles in general and more specifically on the EN 1993-1-3 and EN 1993-1-5 Eurocodes.

This new method of design by calculation for steel decking with embossments, is based on tests carried out within the European GRISPE project (2013-2016).

The background of this method is described in Annex 1.

Chapter 1 details the type of profiles concerned, the state of the art, the main research results of GRISPE and the general design requirements and rules;

Chapter 2 outlines the preliminary considerations that must be taken into account during the predesign phases, including in particular the verification of the field of application of the new design method;

Chapter 3 states the technological requirements that have to be respected including support frame, profiles characteristics and assemblies;

Chapter 4 lists the materials properties of the profiles;

Chapter 5 specifies the determination of actions and combinations

Chapter 6 gives the basis of the design

Chapter 7 lists the specific design consideration not covered by the manual

Chapter 8 explains in detail the new design method (principles, field of application, and description of how to apply the new formulas).

A bibliography and an Annex are included.

Preface

This Design manual have been carried out with the support of RFCS funding n°**754092**

This new design method has been presented at the evolution group of EN 1993-1-3 in 2016-2017 and is being considered for inclusion into the Eurocodes.

This Design manual has been written by PALISSON Anna and has been discussed in a GRISPE PLUS working group composed by the following members:

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Figures

The figures have been produced by the following companies

Figure 1.1.1 – BACACIER

Figure 1.3.1 – KIT

Figure 1.3.2 – KIT

Figure 1.3.3 – KIT

Figure 2.2.1.1 – Copy of EN 1993-1-3

Figure 2.2.2.1 – Copy of EN 1993-1-3

Figure 6.2.1 - Sokol Palisson Consultants

Figure 6.2.2 - Sokol Palisson Consultants

Figure 8.1.1 – BACACIER

Figure 8.1.2 - Sokol Palisson Consultants

CONTENT

9. BIBLIOGRAPHY

ANNEX 1

SCOPE OF THE PUBLICATION

The aim of this publication is to present the new design method for steel decks with embossments that has been proposed for inclusion in Eurocode EN 1993-1-3.

This design manual deals with currently occurring situations.

For specific issues (e.g. opening) or for exceptional situations (seismic, fire, etc.) it is necessary to follow the relevant clauses of the Eurocodes and/or EN 1090-4.

NOTATIONS

The following symbols are used :

t : design thickness

t_{nom} : nominal thickness

t_{eff}: effective thickness

h_w : profile height

f_{yb} : yield strength

E : Young's modulus

$LS_{embossment}$: lenght of the Superior embossment

$zS_{embossment}$: distance from the lower flange to the Superior embossment

$LI_{embossment}$: lenght of the Inferior embossment

$zI_{embossment}$: distance from the lower flange to the Inferior embossment:

h : height of the embossment / indentation

ρ : reduction factor determined for the embossment

t_{red} : reduced thickness

b_{pi} : widths of plane cross section parts

$b_{i,eff}$: effective width

A_g : area of the gross cross-section

A_{eff} : effective area

z_G : position of the neutral axis

σ_{xx} : stress

χ_d : reduction factor for the distortional buckling resistance

$M_{c,Rd}$: resistance moment

M_{span} : span resistance moment

e_c : distance from the compressed flange and the position of the neutral axis

s_n : width of the part of the web between the compressed flange and the position of the neutral axis

s_{eff} : effective cross section for the web

W_{eff} : effective section modulus

$R_{w,Rd}$: local transverse resistance

1. INTRODUCTION

1.1. Type of profiled steel sheets

This design manual deals with steel sheeting with embossments and indentations.

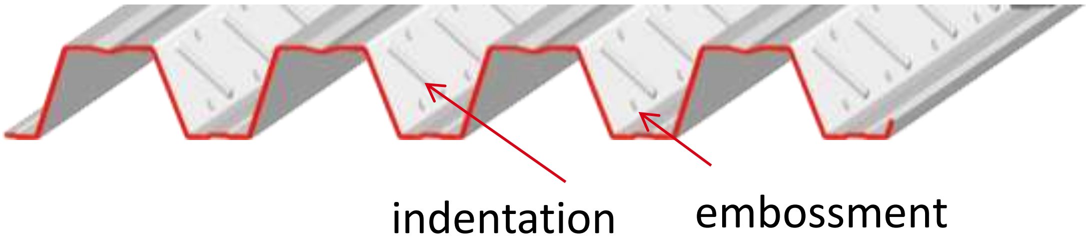


Figure 1.1.1 *– Steel sheeting with embossments and / or indentations*

1.2. State of the art pre-GRISPE

Steel decking has become an integral structural element in composite slabs for both roofs and floors, with a variety of corrugations of varying depth, of embossments and indentations. It is often the preferred material for interior design, commercial and industrial refurbishments and for the building trade in general because it is sturdy, lightweight and need limited maintenance. In order to increase the shear connection between the steel and the concrete in the composite slabs, steel decks are equipped with embossments or indentations.
At the construction stage where the sheeting used as shuttering has to support the fresh concrete weight and the construction loads, the effect of the embossments and indentations is not favorable for the bending moment resistance. The few studies [1] [2] [3] [4] which have been carried out have shown that embossments decrease by about 10% the bending resistance of the profiled sheeting and increase by about 10% the web crippling resistance. But the experimental programme which led to these observations was not significant enough to derive solid conclusions and did not define the effect on combined action of support reaction and negative moment.
This type of sheeting has been optimised over the years and many new shapes have appeared on the markets which are not covered by the Eurocodes despite their growing commercial importance.
In EN 1994-1 for the design of the decking profile in composite stage, a link with EN 1993-1-3 is made.
EN 1993-1-3 deals in 1.5.1 (4) with the sheeting but in section 1.5.2 « Types of stffeners » the profiles with indentations and embossments used in the sheeting for composite slabs are not taken into account.
In summary within the current texts of the Eurocodes, the only option for manufacturers to design this family of products is to carry out expensive and time consuming tests.

1.3. Main results of GRISPE

In order to determine and compare the resistance values of steel decks with and without embossments and indentations (Figure 1.3.1 ; Figure 1.3.2 and Figure 1.3.4), an extensive programme of 144 tests was performed according to EN 1993-1-3 Annex A on steel trapezoidal sheeting with and without embossments and indentations.
In addition, 54 tensile testing on coupons with and without embossments were performed in order to determine the local influence of embossments.
Based on the tensile testing a reduction coefficient of the thickness of the profile with

embossments /indentations was defined. This innovative design model was validated through a detailed analysis of the experimental results of the 144 global tests, and calculations methods have been developed to determine the span moment resistance, the web crippling resistance and the combined moment + reaction resistance of the profile with embossments / indentations.

Figure 1.3.1 – *Single span test*

Figure 1.3.2 – *End support test*

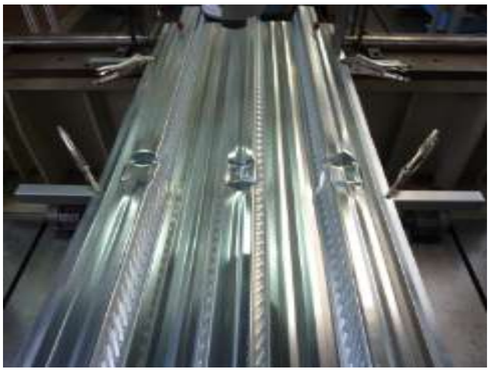


Figure 1.3.3 – *Intermediate support test*

1.4. General design requirements and rules

(1) The design of steel sheeting with embossments / indentations should be in accordance with the general rules given in EN 1993-1-1.

(2) Appropriate partial factors shall be adopted for ultimate limit states and serviceability limit states according to EN 1993-1-3.

2. PRELIMINARY CONSIDERATION – PRE-DESIGN

2.1. Field of application of the new design method

This manual gives design requirements for steel sheeting with embossments / indentations. The execution of steel structures made of sheeting is covered in EN 1090.

This manual gives methods for design by calculation This method applies within stated ranges of material properties and geometrical proportions

This manual does not cover load arrangement for loads during execution and maintenance.

The calculation rules given in this manual are only valid if the tolerances of the cold formed members comply with EN 1993-1-3.

2.2. Technological dispositions of the profile sheet

2.2.1. Form of sections

(1) Profiled sheets have within the permitted tolerances a constant nominal thickness over their entire length and may have either a uniform cross section or a tapering cross section along their length.

(2) The cross-sections of profiled sheets essentially comprise a number of plane elements joined by curved elements.

(3) Examples of cross-sections for sheets are illustrated in figure 2.2.1.1.

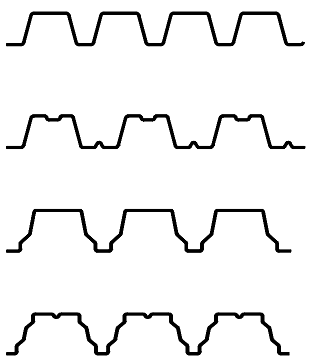


Figure 2.2.1.1 – *Example of profiles sheets*

(4) Cross-sections of sheets may either be unstiffened or incorporate longitudinal stiffeners in their webs or flanges, or in both.

2.2.2. Cross-section dimensions

The cross-section dimensions should satisfy the general requirements given in EN 1993-1-3, section 1.5.3.

(1) The thickness t is a steel design thickness (the steel core thickness extracted minus tolerance if needed as specified in clause 3.2.4 of EN 1993-1-3), if not otherwise stated.

(2) The provisions for design by calculation given in this design manual should not be applied to cross-sections outside the range of width-to-thickness ratios *b/t*, *h/t*, *c/t* and *d/t* given in Table (Table 5.1 of EN 1993-1-3).
(3)

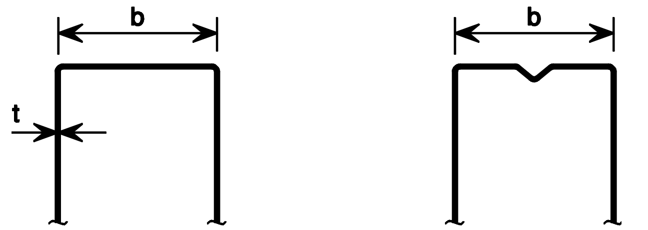
	$b/t \leq 500$
	$45° \leq \phi \leq 90°$ $h/t \leq 500 \sin\phi$

***Table 2.2.2.1** – Checking of geometrical proportions*

3. BASIC TECHNOLOGICAL REQUIREMENTS

Profiled sheet and CE marking

Steel decks are CE marked according to the standard EN 1090-1.

4. MATERIAL PROPERTIES

Steel sheet

The material properties should satisfy the requirements given in EN 1993-1-3, section 3.

The usual types of steel are the grades S320GD + ZA and S350GD + ZA

The thickness tolerances should satisfy the requirements given in EN 1993-1-3, section 3.2.4.

5. ACTION LOADS AND COMBINATIONS

The actions and combinations which should be taken into account must be determined according to EN 1991-1-6 Eurocode 1: Actions on the structures, Part 1-6 : General actions – Actions during execution, 2005, and their National Annexes.

6. BASIS OF THE DESIGN

6.1. Principles

This new design method is given to calculate:

- Resistance of sheeting with indentations and/or embossments to bending moment
- Resistance of sheeting with indentations and/or embossments to local load or support reaction
- Resistance of sheeting with indentations and/or embossments to combined bending moment and local load or support reaction

6.2. Field of application of the new design method

This new design method is for sheeting with indentations (Figure (6.2.1) and / or for sheeting with embossments (Figure 6.2.2)

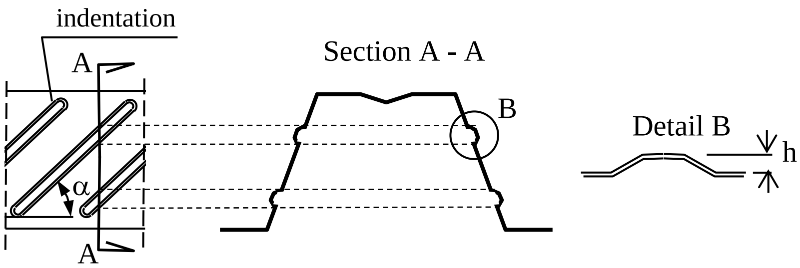


Figure 6.2.1 *– Sheeting with indentations*

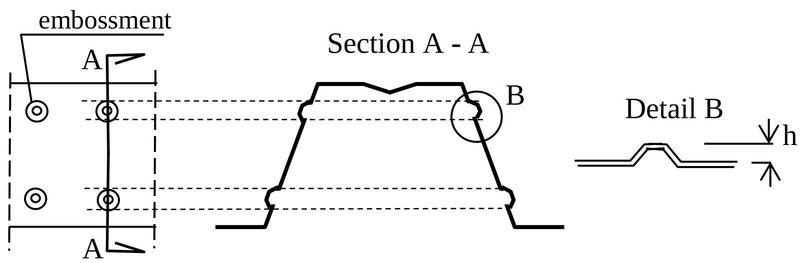


Figure 6.2.2 *– Sheeting with embossments*

Range of validity

$0{,}71\ \text{mm} \leq t_{cor} \leq 1{,}21\ \text{mm}$

$h \leq 4{,}0\ \text{mm}$

$30° \leq \alpha \leq 60°$

For intermediate thicknesses the reduction factor ρ may be determinated by means of linear interpolation between the neighbouring t values given in the Table 6.3.

For t_{cor} > 1,21 mm the values given for t_{cor} = 1,21 mm may be conservatively adopted.

6.3. Design procedure

6.3.1. Effective section of sheeting with indentation and/or embossment

(1) In the first step the effective width of plane wall with indentations (Figure 6.2.1) or embossments (Figure 6.2.2) should be calculated according to 5.5.1(2) of EN 1993-1-3 without taking into account the embossments / indentations

(2) In the second step, the indentation or embossment should be taken into account considering the embossments / indentations (Figures 6.2.1 / 6.2.2) as plate elements with reduced thickness $t_{red} = \rho * t_{cor}$ where:

$\rho = A*h + B$

h is height of the indentation / embossment in mm (see Figures 6.2.1 and 6.2.2)

A and B are coefficients given in table 6.3.1

Type of local deformation	t (mm)	h (mm)	A	B
Indentation	0.71	0 - 1.5	-0.533	1.000
		1.5 - 2.75	-0.112	0.368
		2.75 - 4.0	-0.025	0.128
	0.96	0 - 1.5	-0.467	1.000
		1.5 - 2.75	-0.186	0.580
		2.75 - 4.0	-0.020	0.122
	1.21	0 - 1.5	-0.401	1.000
		1.5 - 2.75	-0.260	0.792
		2.75 - 4.0	-0.015	0.116
Embossment	0.71	0 - 1.5	-0.267	1.000
		1.5 - 2.75	-0.056	0.684
		2.75 - 4.0	-0.013	0.564
	0.96	0 - 1.5	-0.234	1.000
		1.5 - 2.75	-0.093	0.790
		2.75 - 4.0	-0.010	0.561
	1.21	0 - 1.5	-0.201	1.000
		1.5 - 2.75	-0.130	0.896
		2.75 - 4.0	-0.008	0.558

Table 6.3.1 *– Values of coefficients A and B*

(3) The cross section for calculation of the effective section should be positioned to cause the most unfavorable effect

6.3.2. Resistance moment of sheeting with indentation and/or embossment

The design moment resistance of a cross-section for bending about one principal axis $M_{c,Rd}$ is determined according to EN 1993-1-3 "6.1.4 Bending moment", as follows :

$$M_{c,Rd} = W_{eff} f_{yb} / \gamma_{M0}$$

The effective section modulus W_{eff} should be based on an effective cross-section that is subject only to bending moment about the relevant principal axis, with a maximum stress $\square_{max,Ed}$ equal to f_{yb} / $\square_{M0}$, allowing for the effects of local and distortional buckling as specified in Section 5.5. and in 7.1

6.3.3. Local load or support reaction

Local transverse resistance of a web of a sheeting with embossments and / or indentations should be calculated according to the formula (6.18) of EN 1993-1-3

$$R_{w,Rd} = \alpha t^2 \sqrt{f_{yb} E} \left(1 - 0,1\sqrt{r/t}\right)\left[0,5 + \sqrt{0,02\, l_a / t}\right]\left(2,4 + (\phi/90)^2\right)/\gamma_{M1} \qquad (6.18)$$

6.3.4. Combined bending moment and local load or support reaction

(1) In case of sheeting with indentations and / or embossments, the equations (6.28a), (6.28b) and (6.28c) of EN 1993-1-3 may be used with:

$M_{c,Rd}$ = resistance moment determined considering the indentations and / or embossments according to 6.3.2

$R_{w,Rd}$ = local transverse resistance determined without considering the indentations and / or embossments (6.3.3)

(2) Cross-sections subject to the combined action of a bending moment M_{Ed} and a transverse force due to a local load or support reaction F_{Ed} should satisfy the following:

$$M_{Ed} / M_{c,Rd} \leq 1$$

$$F_{Ed} / R_{w,Rd} \leq 1$$

$$\frac{M_{Ed}}{M_{c,Rd}} + \frac{F_{Ed}}{R_{w,Rd}} \leq 1,25$$

7. SPECIFIC DESIGN CONSIDERATION

Situations not covered by the present Manual

- **Fire**
- **Seismic**
- **Environmental aspect**
- **Thermal**
- **Acoustic**
- **Others**

8. DESIGN EXAMPLE

8.1. Explanation of the "2 stiffeners – span – end support" software calculation

This software allows to calculate span moment resistance and end support reaction for a profile with two stiffeners in the upper flange, with longitudinal embossments (indentations).

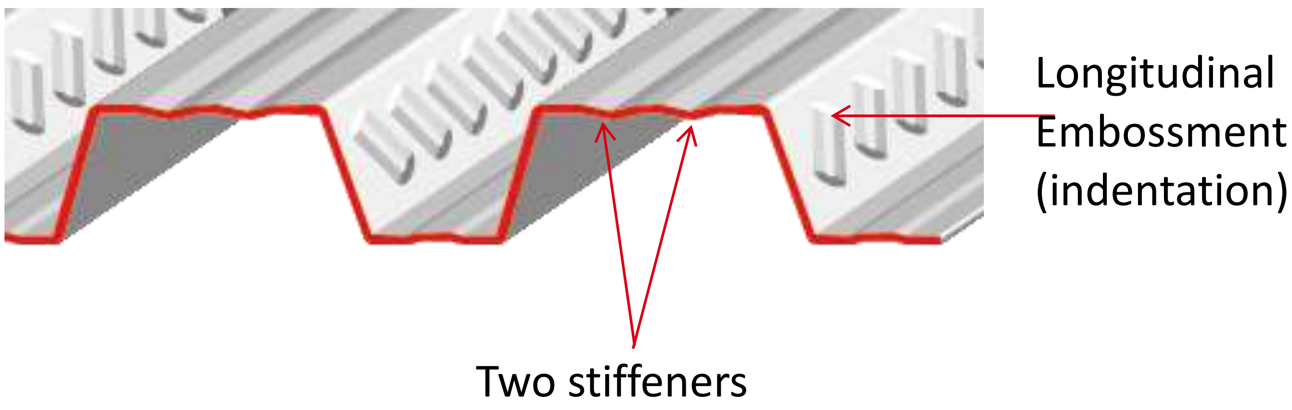


Figure 8.1.1 *- Steel sheeting with two stiffeners in the upper flange and with longitudinal embossments (indentations)*

1) Determination of embossment ratio ρ

The red cell

Choose t_{nom} = 0.75 mm or t_{nom} = 1mm	

must be filled with value of t_{nom} of the profile to calculate : 0.75 or 1

The red cell

Height of the embossment h_e < 4 mm	

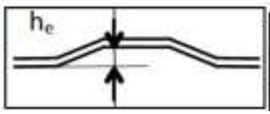
must be filled with the height of the embossments which must be < 4mm

Then the value of the ratio ρ will be automatically displayed by the software

For example :

➢ if t_{nom} = 1 mm and h_e=3mm

Choose t_{nom} = 0.75 mm or t_{nom} = 1mm	1



if t_{nom} = 0,75 mm	
h_e < 4 mm	ρ

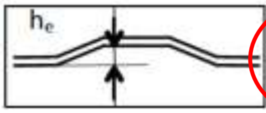
Height of the embossment he < 4 mm	3

if t_{nom} =1 mm	
h_e < 4 mm	ρ
3	0.062

Figure 8.1.2 *- Excel cells to be filled if t_{nom} = 1 mm*

- if t_{nom} = 0,75 mm and h_e=2mm

Choose t_{nom} = 0.75 mm or t_{nom} = 1mm	0.75



if t_{nom} = 0,75 mm	
h_e < 4 mm	ρ
2	0.150

Height of the embossment he < 4 mm	2

if t_{nom} =1 mm	
h_e < 4 mm	ρ

***Figure 8.1.3** - Excel cells to be filled if t_{nom} = 0.75 mm*

This value will be automatically displayed in the table in paragraph "2° DATA"

ratio ρ
0,150

2) DATA

All the red cells have to be filled with the profile dimensions (*Figure 8.1.4 and Figure 8.1.5*): internal bend radius R, angles θ, design thickness t, nominal thickness t_{nom}, the pitch, web height h_w, depth of the superior stiffener d_s, depth of the inferior stiffener d_i, yield strength f_{yb}, Young's modulus E, the length lr_s the lenght of the Superior embossment $LS_{embossment}$, , distance from the lower flange to the Superior embossment, the lenght of the Inferior embossment $LI_{embossment}$,, and distance from the lower flange to the Inferior embossment:

R1 (mm)	θ_1 (rad)	$R2_{sup}$ (mm)	$R2_{inf}$ (mm)	θ_2 (rad)	t_{nom} (mm)	t (mm)

Pitch (mm)	hw (mm)	d_s (mm)	lr_s (mm)	d_i (mm)	f_{yb} (N/mm²)	E (N/mm²)	γ_{M0}

$LS_{embossment}$ (mm)	$LI_{embossment}$ (mm)	$zS_{embossment}$ (mm)	$zI_{embossment}$ (mm)

***Table 8.1.1** - Excel cells to be filled with the profile dimensions*

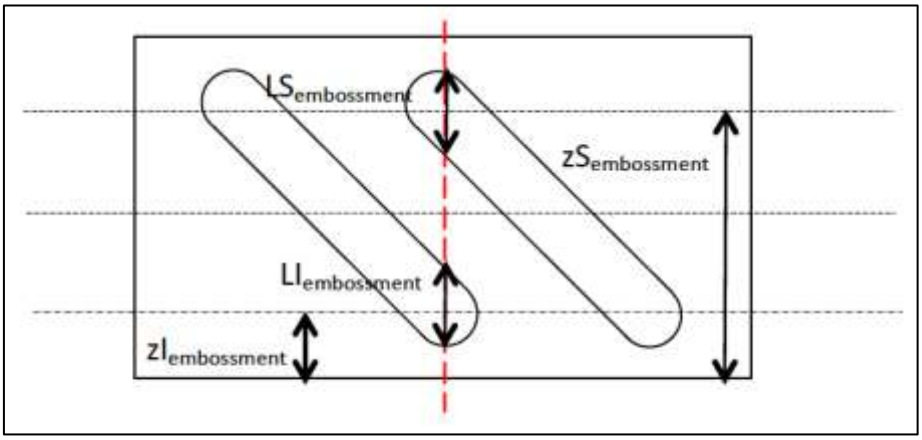


Figure 8.1.4 - *Longitudinal embossments dimensions*

Then the value of the ratio ρ will be automatically displayed by the software

Fill the red cells of the following table with dimensions (b_{pi}) of all elements of ½ pitch. The element numbers are given in the Figure 8.1.5. The length of the elements are measured from the midpoints « P » of the adjacent corner elements as indicated in Figure 8.1.6.

Element	b_{pi} (mm)
1	
2	
3	
4	
5	
6	
7	
8	

Table 8.1.2 - *Excel cells to be filled with the elements dimensions*

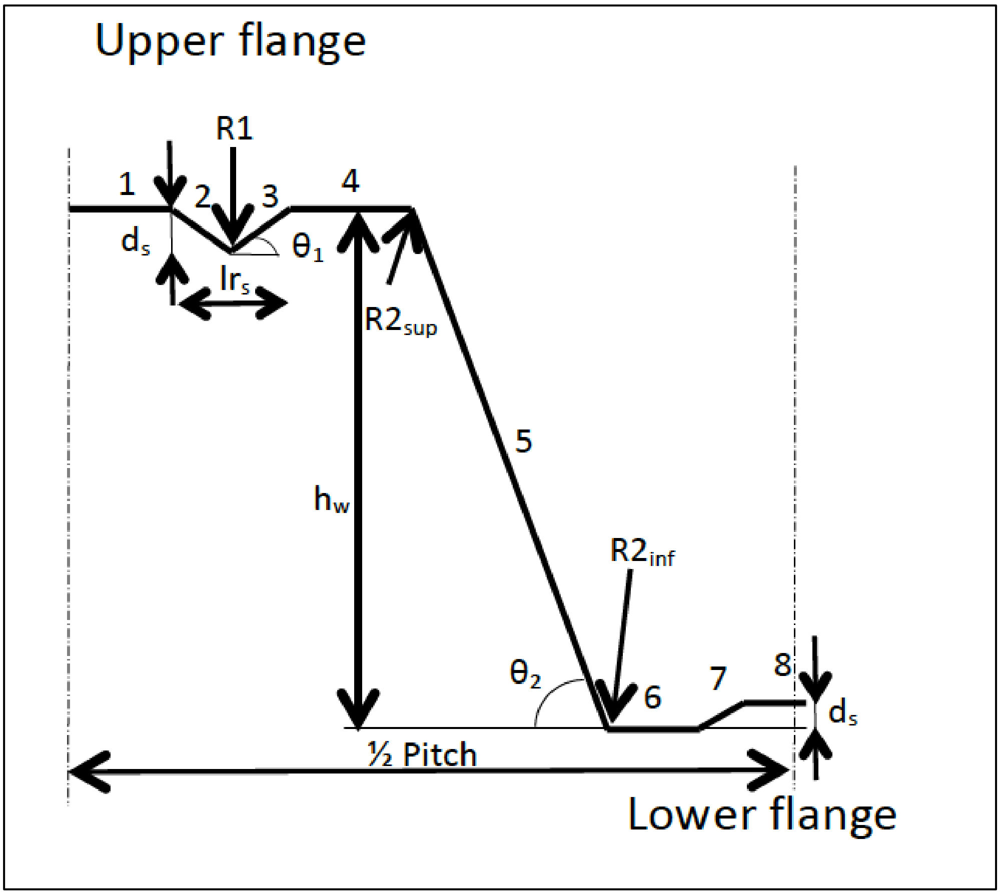


Figure 8.1.5 *- Element numbers and data*

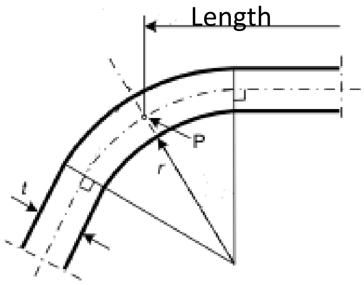


Figure 8.1.6 *- Length of the elements measured from the midpoints « P »*

3) Checking of geometrical proportions

The software automatically displays the checking of geometrical proportions

	b/t=	94,37
	θ_2=	72,00
	h/t=	84,51
	500sin(θ2)=	475,52
r <	$0{,}04\ t\ \sqrt{E/f_y}$	18,64

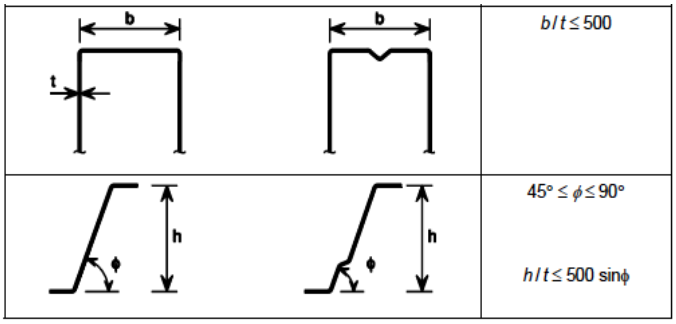


Table 8.1.3 *- Automatic checking of geometrical proportions*

<u>4) RESULTS</u>

The software automatically displays the results :

- ⇨ span moment resistance **M_{span}= 4.45 kNm/m**
- ⇨ end support reaction **$R_{endsupport}$= 6.89 kN/m**

8.2. Auto-control of the software - details of the calculation steps

The auto control is based on the calculation of span moment resistance value of a profile with thickness=0,75 mm and with height of embossments 2,2 mm

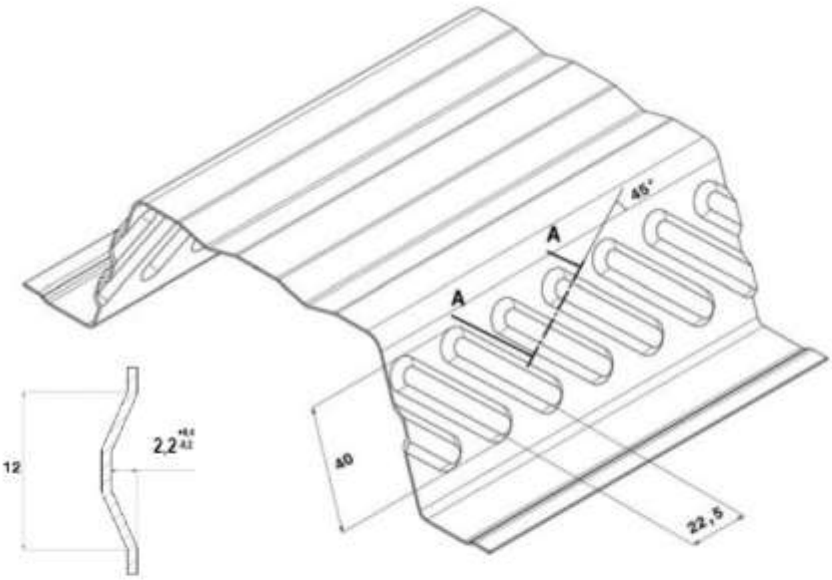


Figure 8.2.1 *- Calculated profile*

1) Determination of embossment ratio ρ

Software:

if t_{nom} = 0,75 mm	
h_e < 4 mm	ρ
2.2	0.122

Table 8.2.1 *- Ratio ρ determined by the software*

Calculation:

ρ = A*h + B, A and B are coefficients given in table 7.3.1

For h= 2,2 (1.5<h<2.75 ➔ A= - 0,112; B= 0.368 $\boxed{\rho\mathbf{=0,122}}$

2) DATA

Software and calculation:

R1 (mm)	θ_1 (rad)	$R2_{sup}$ (mm)	$R2_{inf}$ (mm)	θ_2 (rad)	t_{nom} (mm)	t (mm)
0,00	0,20	5,00	5,00	1,26	0,75	0,71

Pitch (mm)	hw (mm)	d_s (mm)	lr_s (mm)	d_i (mm)	f_{yb} (N/mm²)	E (N/mm²)	γ_{M0}
207,00	60,00	2,50	25,00	1,00	320,00	210000,00	1,00

$hS_{embossment}$ (mm)	$hI_{embossment}$ (mm)	$zS_{embossment}$ (mm)	$zI_{embossment}$ (mm)
16.97	16.97	41.25	18.75

Table 8.2.2 *- Excel cells filled with the profile dimensions*

Element	b_{pi} (mm)
1	8.50
2	12.75
3	12.75
4	20.00
5	61.70
6	20.50
7	1.41
8	9.00

Table 8.2.3 *- Excel cells filled with the elements dimensions*

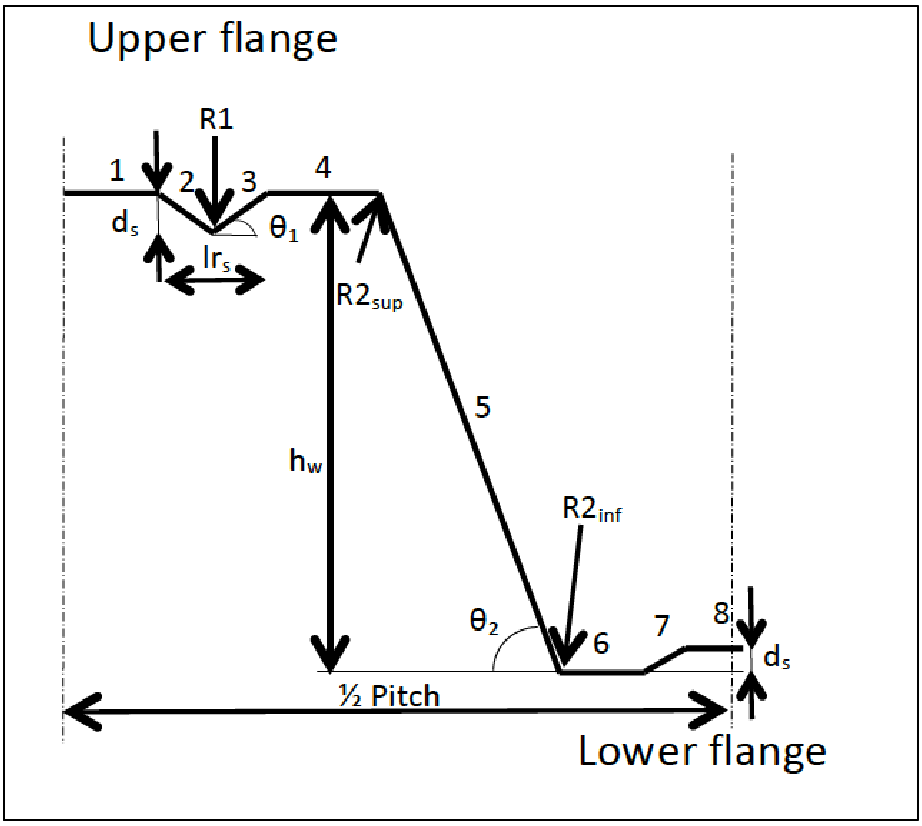


Figure 8.2.2 *- Elements numbers*

4) RESULTS

Software:

- span moment resistance | M_{span}= 4.45 kNm/m |
- end support reaction | $R_{endsupport}$ 6.89 kN/m |

Calculation:

Calculation of A_g the area of the gross cross-section

A_g is the sum of the areas of each element (length x t)

A_g = 104.2 mm²

Position of the neutral axis: z_G = 34.7 mm

Calculation of A_{eff} the effective area:

1st Step

A_{eff} is the sum of the effective areas of each element

Upper flange effective area

The upper flange has 2 stiffeners therefore the effective cross-section of the flange is calculated according to EN 1993-1-3 § "5.5.3.4.2 Flanges with intermediate stiffeners"

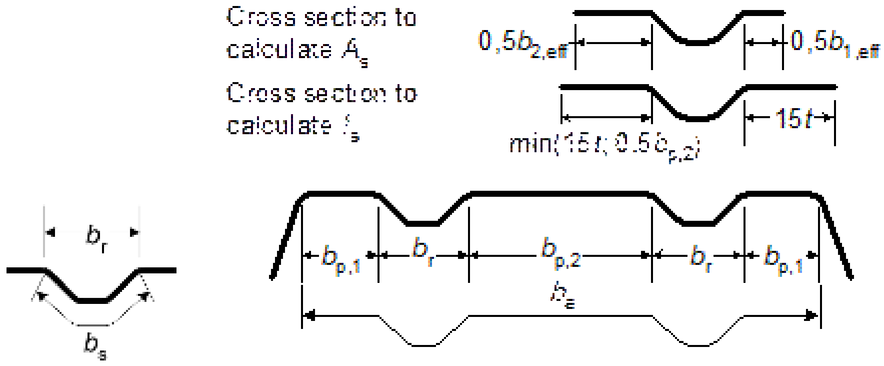


Figure 8.2.3 *- Flange with two stiffeners*

stress in the upper flange is $\sigma_{com} = f_{yb} \times (h_w - z_G)/ z_G = 233$ N / mm²

$b_{p,1} = 20$ mm, $\rho = 1$ ➔ $0,5\ b_{1,eff} = 10$ mm

$b_{p,2} / 2 = 8,5$ mm, $\rho = 1$ ➔ $0,5\ b_{2,eff} = 8,5$ mm

Stiffeners:

The cross section of the stiffener is calculated according to EN 1993-1-3 § "5.5.3.3 Plane elements with intermediate stiffeners »

critical buckling stress $\sigma_{cr,s} = 103$ N/mm²

reduction factor for the distortional buckling resistance $\chi_d = 0,374$

<u>Web Effective area</u>

The web effective area is calculated according to "5.5.3.4.3 Webs with up to two intermediate stiffeners" of EN 1993-1-3

The effective width of plane wall with indentations (Figure 8.2.7) are first calculated according to 5.5.1(2) of EN 1993-1-3

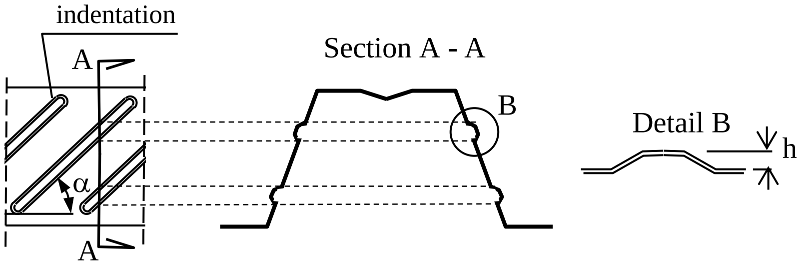


Figure 8.2.4 *– Sheeting with longitudinal embossments (indentations)*

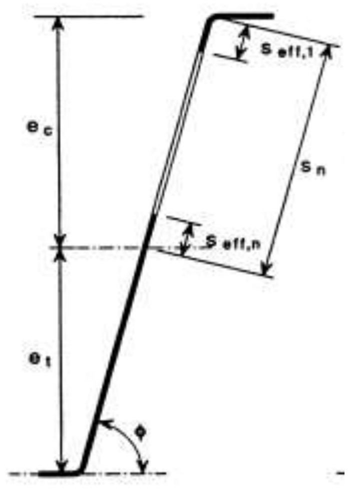


Figure 8.2.5 *- Web effective area*

$e_c = h_w - z_G$=25,3 mm ➔ s_n = 25,9 mm

σ_{com} = f_{yb} x ($h_w - z_G$)/ z_G = 233 N / mm² ➔ $s_{eff,0}$ = 20,24mm ➔ $s_{eff,1}$ = 20,24 mm ➔ $s_{eff,n}$ = 30,36 mm ➔ $s_{eff,1} + s_{eff,n} \geq s_n$ the entire web is effective

$s_{eff,1} = 0{,}4 s_n$

$s_{eff,n} = 0{,}6 s_n$

<u>Lower flange effective area</u>

Lower flange in this case is in tension ➔ the effective area = gross section area

<u>Total effective area</u>

A_{eff} = 89 mm²

Position of the neutral axis of the effective section: z_G = 30,5 mm

<u>Iteration: Next Steps</u>

In the next steps the new position of the neutral axis of the effective section is taken to calculate the new σ_{com} .

<u>The upper flange effective area</u> is calculated as in step 1 but taking the new σ_{com} calculated with new position of the neutral axis z_c

<u>Web Effective area</u> is calculated considering the indentations as plate elements with reduced thickness t_{red} = 0,122 x 0,71= 0,087 mm for the length $L_{embossments}$ (Figure 8.2.6)

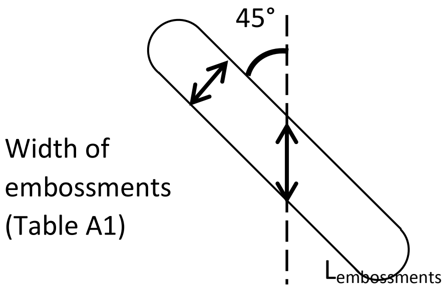


Figure 8.2.6 *- Length of the longitudinal embossments (indentation)*

$L_{embossments}$ = Width / sin (45°) and Width is = 12 mm

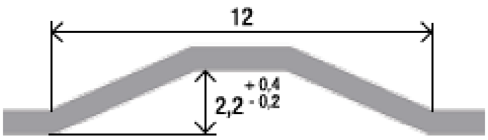


Figure 8.2.7 *- Height of the embossments*

$\boxed{\text{Therefore } L_{embossments} = 16{,}97 \text{ mm}}$

All the values of step 2 and step 3 are indicated in following table. The convergence is considered satisfactory at step 3, the iteration stops at step 3.

		2nd step	3rd step
Upper flange	σ_{com}	309	320
	ρ pour b 2,eff	1	1
	0,5 b $_{2,eff}$	8.50	8.50
	ρ pour b 1,eff	1	1
	0,5 b $_{1,eff}$	10.00	10.00
Upper flange stiffener	$\sigma_{cr,s}$	102.7	102.7
	χ_d	0.37	0.37
	t_{red}	0.27	0.27
Web	e_c	29.5	31.1
	s_n	30.3	32.0
	$s_{eff,0}$	17.6	16.7
	$s_{eff,1}$	17.6	16.7
	$s_{eff,n}$	26.4	25.0
	$s_{eff,1}$ + Seff,n	43.9	41.6
		entire web is effective	entire web is effective
	$s_{eff,1}$	0,4sn	0,4sn
	$s_{eff,n}$	0,6sn	0,6sn
Total effective Area	A $_{eff}$	63.9	63.5
Position of neutral axis	z_c	28.9	28.7

Table 8.2.4 *– Step 2 and Step 3 values*

Calculation of span moment resistance:

$$M_{c,Rd} = W_{eff}\, f_{yb} / \gamma_{M0}$$

For ½ pitch I_{eff} =45029 mm^4

For the profile I_{eff} = 435 mm^3

v = max (28,7;31,3)=31.3 mm

W_{eff} = I_{eff} / v = 13.9 mm^3

$\boxed{M_{span} = 4,45 \text{ kNm/m}}$

The result is the same as the software result

M_{span}=	4.45	kNm/m

Calculation of end support resistance:

Local transverse resistance of a web of a sheeting with longitudinal embossments (indentations) should be calculated according to the usual formula (6.18) of EN 1993-1-3

$$R_{w,Rd} = \alpha\, t^2 \sqrt{f_{yb} E}\, \left(1 - 0{,}1\sqrt{r/t}\right)\left[0{,}5 + \sqrt{0{,}02\, l_a / t}\,\right]\left(2{,}4 + (\phi/90)^2\right) / \gamma_{M1} \qquad (6.18)$$

α = 0,075

t = 0,71 mm

r = 5 mm

l_a = 10mm

ϕ = 72

Per web : $R_{w,Rd}$ = 713 N

Per meter: $\boxed{R_{w,Rd} = 6,89 \text{ kN/m}}$

The result is the same as to the software result

$R_{endsupport}$	6.89	kN/m

9. BIBLIOGRAPHY

[1] Davies J.M and Jiang C., Design Procedures for Profiled Metal Sheeting and Decking in Thin-Walled Structures Vol. 27, No. I, pp. 43-53, Elsevier, 1997.
[2] Luure P. and Crisinel M. Essais comparatifs sur tôles nervurées de plancher mixtes avec et sans bossages, ICOM/EPFL, Nov. 1993.
[3] Mistakidis, E.S, Kyriakos, G. and Dimitriadis, L., Thin-Walled Structures: Bending resistance of composite slabs made with thin-walled steel sheeting with indentations or embossments, University of Thessaly, 38334 Volos, 2007.
[4] Composite slabs and beams using steel decking: best practice for design and construction, MCRMA Technical Paper No. 13 SCI Publication, March 2009.

Annex 1

Background of the new design method for steel decks with embossments

D1.1	GRISPE WP1 Background document	Anna PALISSON (Sokol Palisson Consultants)
D1.2	GRISPE WP1 Test programme definition	Anna PALISSON (Sokol Palisson Consultants)
D1.3	GRISPE Test report of steel trapezoidal sheeting with and without em-bossments and outward stiffeners	Christian FAUTH (KIT)
D1.4	GRISPE WP1 Test analysis and interpretation	Anna PALISSON (Sokol Palisson Consultants)
D1.5	GRISPE Background guidance for EN 1993-1-3 to design of sheeting with embossments and indentations	Anna PALISSON (Sokol Palisson Consultants)

PART 2: WORKED EXAMPLE FOR STEEL DECKS WITH EMBOSSMENTS

SUMMARY

The purpose of this worked example is to present a new method of design by calculation for steel decking with embossments, as developed in the European project GRISPE PLUS.

The worked example on the Eurocode principles in general and more specifically on the EN 1993-1-3 and EN 1993-1-5 Eurocodes.

This new method of design by calculation for steel decking with embossments, is based on tests carried out within the European GRISPE project (2013-2016).

The background of this method is described in Annex 1.

Chapter 1 details the sheeting cross-section, data and embossments dimensions

Chapter 2 explains the calculation of the gross section

Chapter 3 explains the calculation of the effective section

Chapter 4 explains the calculation of the moment resistance

Chapter 5 explains the calculation of the end support reaction

An annex is included.

Preface

This Worked Example have been carried out with the support of RFCS funding n°**754092**

This new design method has been presented at the evolution group of EN 1993-1-3 in 2016-2017 and is being considered for inclusion into the Eurocodes.

This Worked Example has been written by Anna PALISSON and has been discussed in a GRISPE PLUS working group composed by the following members:

Mickael BLANC	France
Silvia CAPRILI	Italy
David IZABEL	France
Markus KUHNENNE	Germany
Anna PALISSON	France
Valérie PRUDOR	France
Irene PUNCELLO	Italy
Dominik PYSCHNY	Germany
Thibaut RENAUX	France
Daniel SPAGNI	France

Corresponding members have included:

SOKOL	Léopold	France

Figures

The figures have been produced by the following companies

Figure 1.1 – BACACIER

Figure 1.1.1 – Sokol Palisson Consultants

Figure 1.3.1 – BACACIER

Figure 1.3.2 - Sokol Palisson Consultants

Figure 1.3.3 - Sokol Palisson Consultants

Figure 2.1 – Copy of EN 1993-1-3

Figure 3.1.1 – Copy of EN 1993-1-3

Figure 3.1.2 - Sokol Palisson Consultants

Figure 3.1.3 - Copy of EN 1993-1-3

Figure 3.1.4 - Sokol Palisson Consultants

Figure 3.2.1 - Sokol Palisson Consultants

Figure 5.1 – Copy of EN 1993-1-3

CONTENT

SCOPE OF THE PUBLICATION

The aim of this publication is to present an example of the application of the new design method for steel decks with embossments, that has been proposed for inclusion in Eurocode EN 1993-1-3.

This Worked Example eals with currently occurring situations.

For specific issues (e.g. opening) or for exceptional situations (seismic, fire, etc.) it is necessary to follow the relevant clauses of the Eurocodes and/or EN 1090-4.

NOTATIONS

The following symbols are used :

t : design thickness

t_{nom} : nominal thickness

t_{eff}: effective thickness

h_w : profile height

f_{yb} : yield strength

E : Young's modulus

$LS_{embossment}$: lenght of the Superior embossment

$zS_{embossment}$: distance from the lower flange to the Superior embossment

$LI_{embossment}$: lenght of the Inferior embossment

$zI_{embossment}$: distance from the lower flange to the Inferior embossment:

h : height of the embossment / indentation

ρ : reduction factor determined for the embossment

t_{red} : reduced thickness

b_{pi} : widths of plane cross section parts

$b_{i,eff}$: effective width

A_g : area of the gross cross-section

A_{eff} : effective area

z_G : position of the neutral axis

σ_{xx} : stress

χ_d : reduction factor for the distortional buckling resistance

$M_{c,Rd}$: resistance moment

M_{span} : span resistance moment

e_c : distance from the compressed flange and the position of the neutral axis

s_n : width of the part of the web between the compressed flange and the position of the neutral axis

s_{eff} : effective cross section for the web

W_{eff} : effective section modulus

$R_{w,Rd}$: local transverse resistance

1. INTRODUCTION

This example shows how to deal with steel sheeting with longitudinal embossments (indentations) when determining the bending capacity and the web-crippling resistance of a sheeting with two stiffeners in the upper flange.

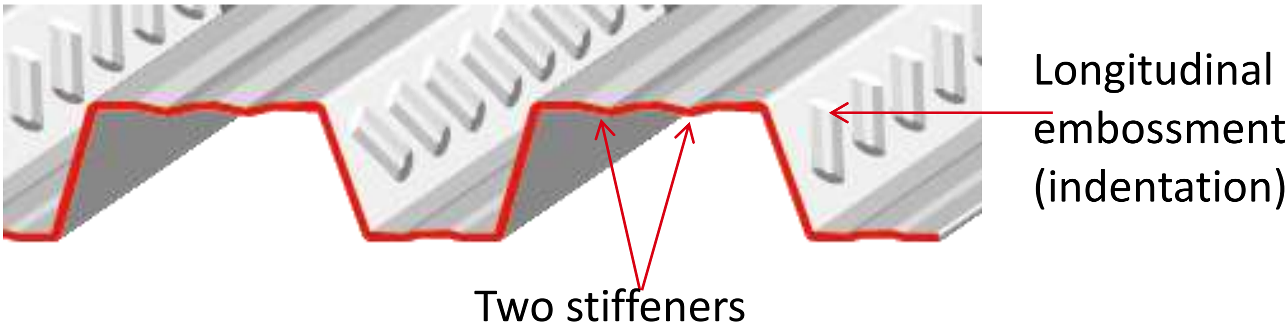


Figure 1.1 - *Steel sheeting with two stiffeners in the upper flange and with longitudinal embossments (indentations)*

1.1. Sheeting cross section

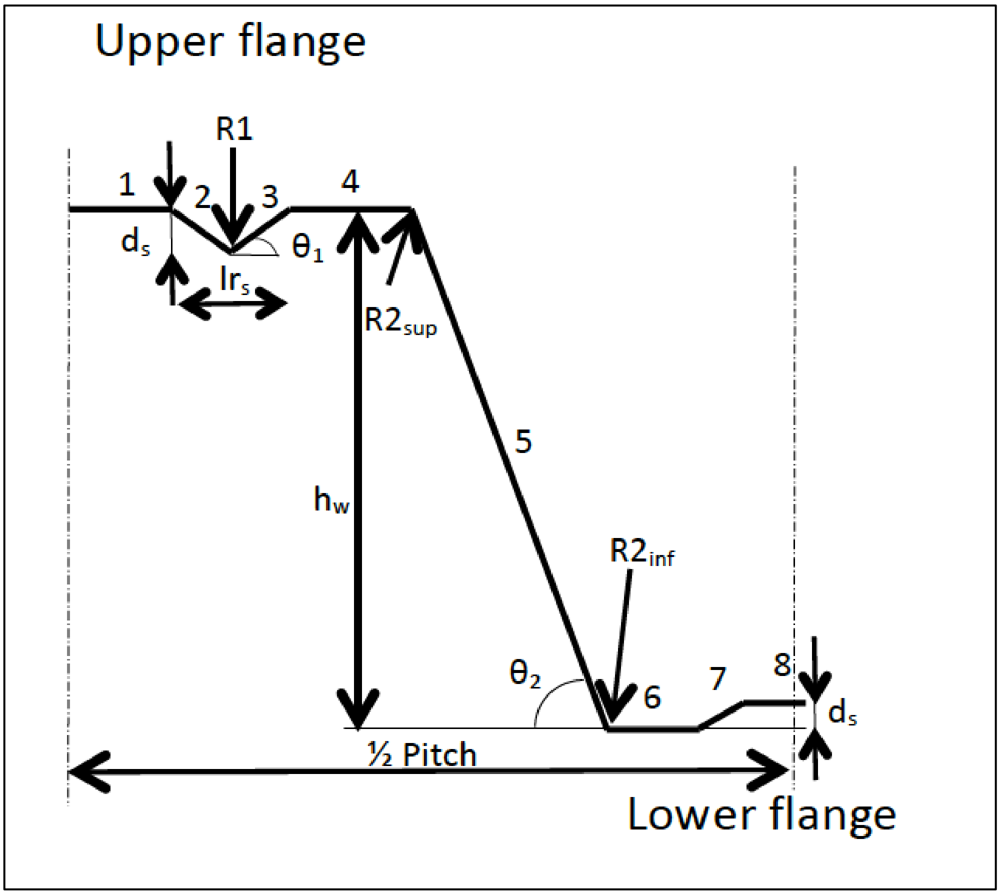


Figure 1.1.1 - *Elements numbers*

1.2. Sheeting values

The example is based on the calculation of span moment resistance value of a profile with the following data:

R1 (mm)	θ_1 (rad)	$R2_{sup}$ (mm)	$R2_{inf}$ (mm)	θ_2 (rad)	t_{nom} (mm)	t (mm)
0,00	0,20	5,00	5,00	1,26	0,75	0,71

Pitch (mm)	hw (mm)	d_s (mm)	lr_s (mm)	d_i (mm)	f_{yb} (N/mm²)	E (N/mm²)	γ_{M0}
207,00	60,00	2,50	25,00	1,00	320,00	210000,00	1,00

$hS_{embossment}$ (mm)	$hI_{embossment}$ (mm)	$zS_{embossment}$ (mm)	$zI_{embossment}$ (mm)
16.97	16.97	41.25	18.75

Table 1.2.1 *- Sheeting data*

Element	b_{pi} (mm)
1	8.50
2	12.75
3	12.75
4	20.00
5	61.70
6	20.50
7	1.41
8	9.00

Table 1.2.2 *- Elements dimensions*

<u>**Checking of geometrical proportions**</u>

b = 107; t = 0.71; h = 60; f_y = 320

	b/t=	94,37
	θ_2=	72,00
	h/t=	84,51
	500sin(θ2)=	475,52
r <	$0{,}04\ t\ E/f_y$	18,64

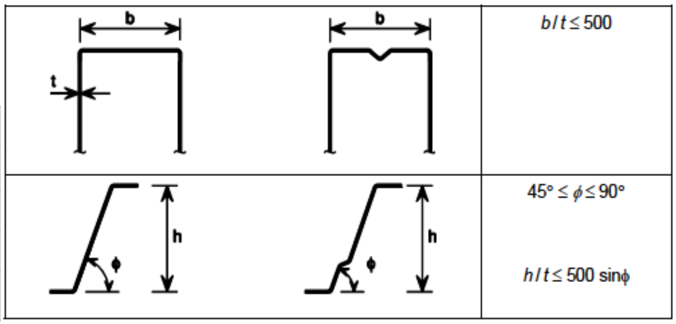


Table 1.2.3 *- Checking of geometrical proportions*

1.3. Embossments dimensions

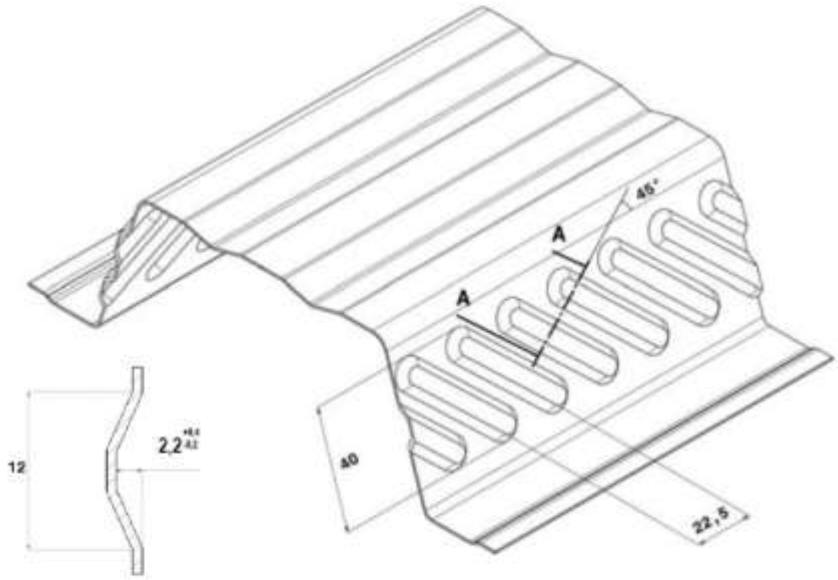


Figure 1.3.1 *- Calculated profile*

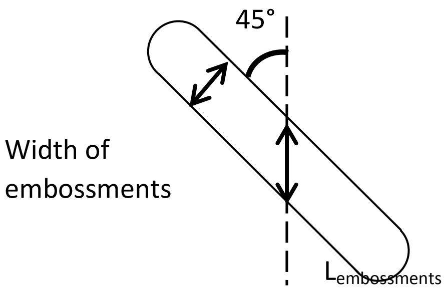


Figure 1.3.2 *- Length of the longitudinal embossments (indentation)*

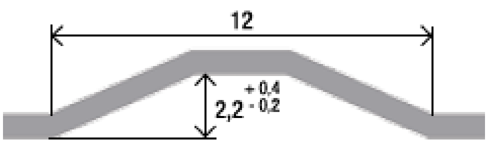


Figure 1.3.3 *- Height of the embossments*

The Range of validity is checked

0.71 mm $\leq$ t_{cor} = 0.75 $\leq$ 1.21 mm

h=2.2 $\leq$ 4,0 mm

30° $\leq$ α*=0.45* $\leq$ 60°

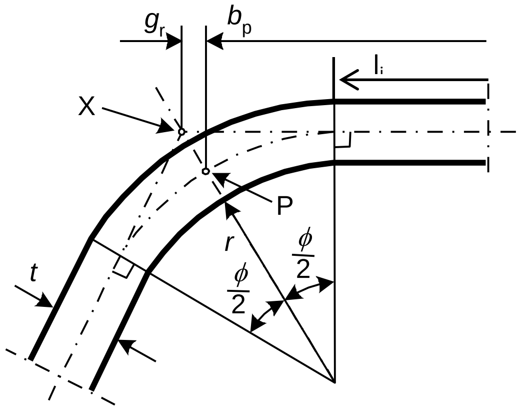
$L_{embossments}$ = Width / sin (45°) where Width is = 12 mm

Therefore $L_{embossments}$ = 16.97 mm

2. CALCULATION OF A_g THE AREA OF THE GROSS-SECTION

A_g is the sum of the areas of each element (length x t)

length = $l_i = b_p - r_m \times \sin\pi/4$



(a) midpoint of corner or bend

X is intersection of midlines

P is midpoint of corner

$r_m = r + t/2$

Figure 2.1 - *Notional widths of plane cross section parts b_p allowing for corner radii*

Element	l_i (mm)	A_i(mm²)	z(mm)	S_i(mm³)	z0(mm)
1	8.5	6.0	60.0	362.1	-25.3
2	12.7	9.1	58.8	531.7	-24.0
Corner 1	0.0	0.0	57.5	0.0	-22.8
3	12.7	9.1	58.8	531.7	-24.0
4	17.1	12.1	60.0	726.8	-25.3
Corner 2_{sup}	6.3	4.5	58.8	262.2	-24.1
5	55.8	39.6	30.0	1189.1	4.7
Corner 2_{inf}	6.3	4.5	1.2	5.4	33.5
6	16.9	12.0	0.0	0.0	34.7
7	1.4	1.0	0.5	0.5	34.2
8	9.0	6.4	1.0	6.4	33.7
TOTAL		104.2		3616.0	34.7

Table 2.1 - *Elements dimensions*

A_g = 104.2 mm²

Position of the neutral axis: $z_G = S / A_g$ = 34,7 mm

3. CALCULATION OF THE EFFECTIVE AREA A_{eff} OF THE SECTION

A_{eff} is the sum of the effective areas of each element.

3.1. Step 1

Upper flange effective area

The upper flange has 2 stiffeners. The effective cross-section of the flange is calculated according to EN 1993-1-3 § "5.5.3.4.2 Flanges with intermediate stiffeners".

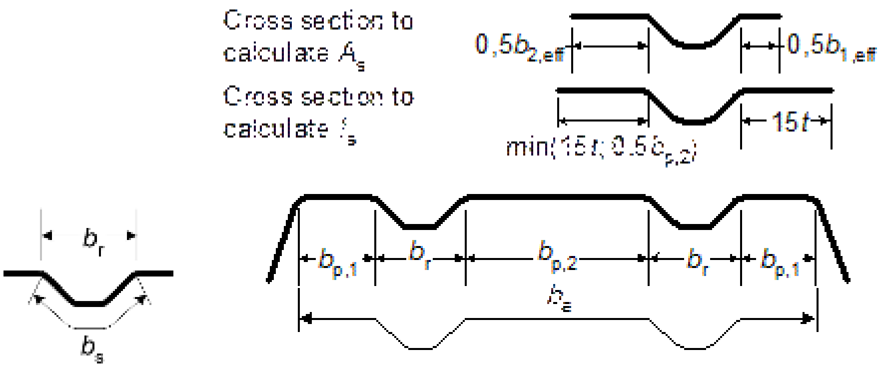


Figure 3.1.1 *- Flange with two stiffeners*

stress in the upper flange is $\sigma_{com} = f_{yb} \times (h_w - z_G)/ z_G = 233$ N / mm²

$b_{p,1} = 20$ mm

$\lambda_{p1} = b_{p1}/t/(28.4\ \varepsilon k_\sigma^{1/2})$ with $\varepsilon = (235/ f_{yb})^{1/2}$

$\psi = \sigma_2/ \sigma_1 = 1$ ➔ Coefficient $k_\sigma = 4$

$\lambda_{p1} = 0.579$

$\lambda_{pred1} = \lambda_{p1} \times \sqrt{\frac{\sigma\ com}{fy/\gamma M0}}$ ➔ $\lambda_{pred1} = 0.494$

$\lambda_{pred1} \leq 0.673$ ➔ $\rho = 1$

$b_{1eff} = \rho * b_{p1} = 20$ ➔ $\boxed{0{,}5\ b_{1,eff} = 10\ m}$

$b_{p,2} = 17$ mm

$\lambda_{p1} = b_{p1}/t/(28.4\ \varepsilon k_\sigma^{1/2})$ with $\varepsilon = (235/ f_{yb})^{1/2}$

$\psi = \sigma_2/ \sigma_1 = 1$ ➔ Coefficient $k_\sigma = 4$

$\lambda_{p2} = 0.492$

$\lambda_{pred2} = \lambda_{p2} \times \sqrt{\frac{\sigma\ com}{fy/\gamma M0}}$ ➔ $\lambda_{pred2} = 0.420$

$\lambda_{pred2} \leq 0.673$ ➔ $\rho = 1$

$b_{2eff} = \rho * b_{p2} = 17$ ➔ $\boxed{0{,}5\ b_{2,eff} = 8.5\ mm}$

Stiffeners of the upper flange:

The cross section of the stiffener is calculated according to EN 1993-1-3 § "5.5.3.3 Plane elements with intermediate stiffeners »

Calculation of critical buckling stress $\sigma_{cr,s}$

$$\sigma_{cr,s} = \frac{4{,}2\ k_w\ E}{A_s} \sqrt{\frac{I_s\ t^3}{8\ b_1^2\ (3\ b_e - 4\ b_1)}}$$

b_s = 25.5 mm, b_r = 25 mm

$b_e = 2b_{p,1} + b_{p,2} + 2b_s = 108$ mm

$b_1 = b_{p,1} + 0{,}5\, b_r = 32.5$ mm

Calculation of A_s

Element	l_i (mm)	A_i(mm²)
plane part of 0.5 b_{2eff}	8,50	6,0
2	12,75	9,1
Corner 1	0,00	0,0
3	12,75	9,1
plane part of 0.5 $b1_{eff}$	10,00	7,10
TOTAL		31,2

Table 3.1.1 *- Elements lengths and areas*

A_s = 31.2 mm²

Calculation of I_s

Element	l_i (mm)	A_i(mm²)	z(mm)	S_i(mm³)	z0(mm)	h	I_i(mm⁴)
plane part of min(15t;0.5b_{2eff})	8,50	6,0	0,0	0,0	0,7	0,7	3,3
2	12,75	9,1	1,3	11,3	-0,5	2,5	7,3
Corner 1	0,00	0,0	2,5	0,0	-1,8	0,0	0,0
3	12,75	9,1	1,3	11,3	-0,5	2,5	7,3
plane part of 15t	10,65	7,6	0,0	0,0	0,7	0,7	4,2
TOTAL		31,7		22,6	0,7		22,1

Table 3.1.2 *- Elements lengths and moment areas*

I_s = 22.1 mm⁴

$$l_b = 3{,}65\ \sqrt[4]{I_s\ b_1^2\ (3\ b_e - 4\ b_1)\ /\ t^3}$$

l_b = 217.8

s_w = 61.7

$l_b / s_w = 3.5 \geq 2 \Rightarrow \quad k_w = k_{wo}$

$$k_{wo} = \sqrt{\frac{(2\,b_e + s_w)(3\,b_e - 4\,b_1)}{b_1\,(4\,b_e - 6\,b_1) + s_w\,(3\,b_e - 4\,b_1)}}$$

$k_{wo} = 1.65$

critical buckling stress $\sigma_{cr,s}$ = 103 N/mm²

$$\bar{\lambda}_d = \sqrt{f_{yb}/\sigma_{cr,s}}$$

$$\bar{l}_d = 1{,}77$$

$$\bar{\lambda}_d \geq 1{,}38 \Rightarrow \chi_d = \frac{0{,}66}{\bar{\lambda}_d}$$

reduction factor for the distortional buckling resistance χ_d = 0,374

Reduced thickness $t_{red} = c_d t \dfrac{f_{yb}/g_{M0}}{s_{com,Ed}}$

Reduced thickness t_{red} = 0.36 mm

<u>Web Effective area</u>

The web effective area is calculated according to "5.5.3.4.3 Webs with up to two intermediate stiffeners" of EN 1993-1-

The sheeting has longitudinal embossments (indentations) as in Figure 3.1.2. The effective width of plane wall with indentations are first calculated according to 5.5.1(2) of EN 1993-1-3.

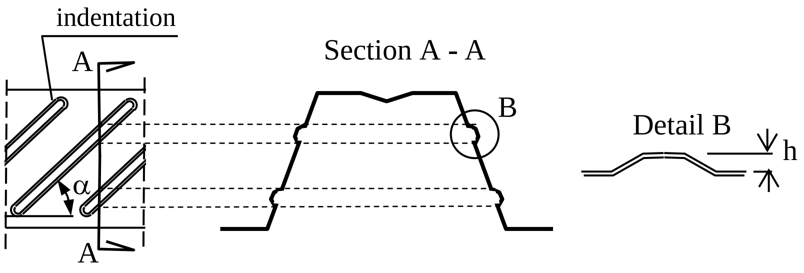


***Figure 3.1.2** – Sheeting with longitudinal embossments (indentations)*

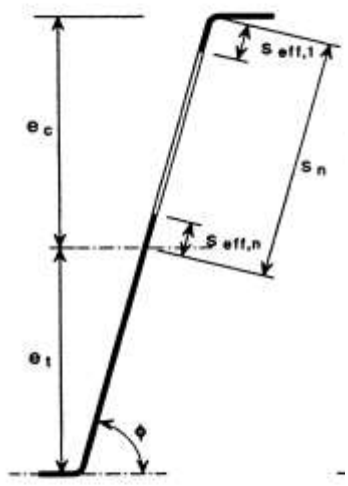


Figure 3.1.3 *- Web effective area*

e_c = h_w – z_G=25,3 mm ➔ s_n = 25,9 mm

σ_{com} = f_{yb} x (h_w – z_G)/ z_G = 233 N / mm²

effective section properties refined iteratively ➔

$$s_{\text{eff},0} = 0{,}95t \sqrt{\frac{E}{\gamma_{\text{M}0}\,\sigma_{\text{com,Ed}}}}$$

➔ $s_{eff,0}$ = 20,24 mm

$s_{eff,1}$ = $s_{eff,0}$ ➔ $s_{eff,1}$ = 20,24 mm

$s_{eff,n}$ = 1.5 $s_{eff,0}$ ➔ $s_{eff,n}$ = 30,4 mm ➔ $s_{eff,1} + s_{eff,n} \geq s_n$ the entire web is effective

$s_{eff,1} = 0{,}4 s_n$

$s_{eff,n} = 0{,}6 s_n$

<u>Lower flange effective area</u>

Lower flange in this case is in tension ➔ all width is effective

<u>Total effective area</u>

Calculation of A_{eff}

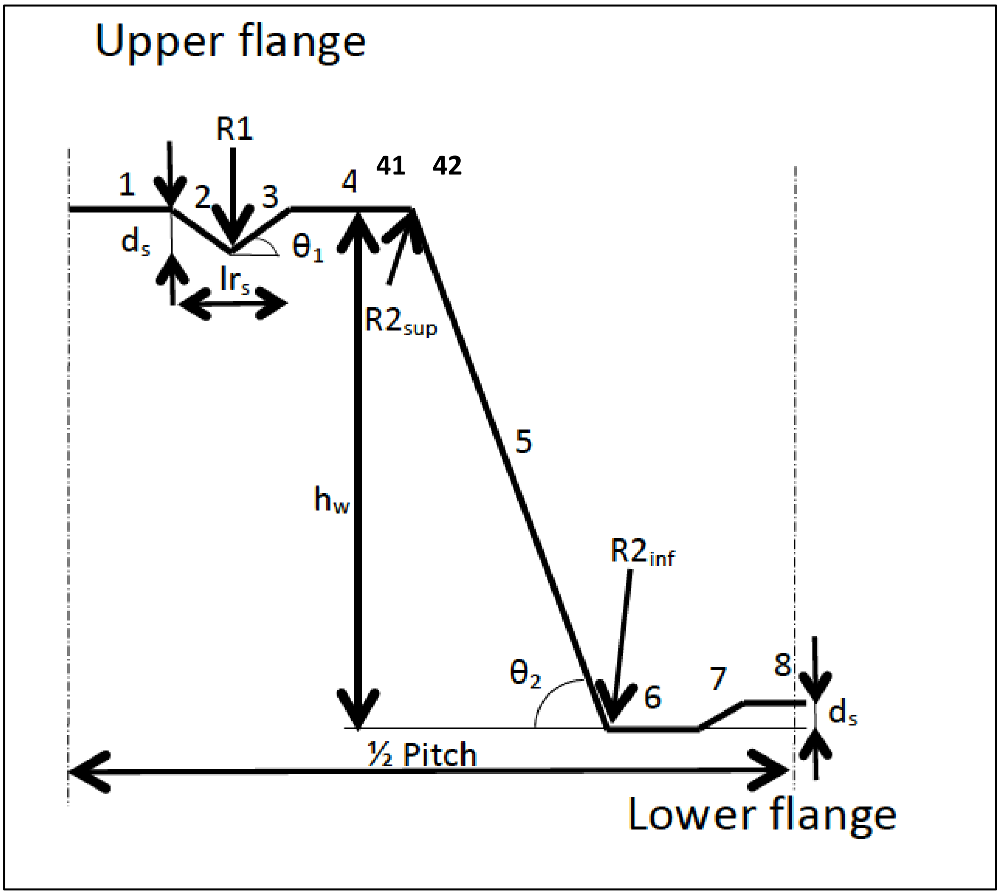


Figure 3.1.4 *- Elements numbers*

Elément	l_i (mm)	t_{eff}	A_i(mm²)	z(mm)	S_i(mm³)	z0(mm)
1	8.50	0.36	3.1	60.0	185.8	-29.5
2	12.75	0.36	4.6	58.8	272.9	-28.2
Corner 1	0.00	0.36	0.0	57.5	0.0	-27.0
3	12.75	0.36	4.6	58.8	272.9	-28.2
41	10.00	0.36	3.6	60.0	218.6	-29.5
42	7.06	0.71	5.0	60.0	300.8	-29.5
Corner 2_{sup}	6.28	0.71	4.5	58.8	262.2	-28.3
5	55.82	0.71	39.6	30.0	1189.1	0.5
Corner 2_{inf}	6.28	0.71	4.5	1.2	5.4	29.3
6	16.87	0.71	12.0	0.0	0.0	30.5
7	1.41	0.71	1.0	0.5	0.5	30.0
8	9.00	0.71	6.4	1.0	6.4	29.5
TOTAL			89.0		2714.6	30.5

Table 3.1.3 *- Elements lengths and areas*

A_{eff} = 89 mm²

Position of the neutral axis of the effective section: z_G = 30,5 mm

3.2. Iteration: Step 2

In the next step the new position of the neutral axis of the effective section is taken to calculate the new σ_{com} .

The upper flange effective area is calculated as in step 1 but taking the new σ_{com} calculated with new position of the neutral axis z_c

All the values of step 2 for the upper flange are indicated in following table.

		2nd step
Upper flange	σ_{com}	309
	ρ pour b 2,eff	1
	0,5 $b_{2,eff}$	8.50
	ρ pour b 1,eff	1
	0,5 $b_{1,eff}$	10.00
Upper flange stiffener	$\sigma_{cr,s}$	102.7
	χ_d	0.37
	t_{red}	0.27

***Table 3.2.1** – 2nd step values for the upper flange*

Web Effective area

The values of step 2 for the web are indicated in following table.

Web	e_c	29.5
	s_n	30.3
	$s_{eff,0}$	17.6
	$s_{eff,1}$	17.6
	$s_{eff,n}$	26.4
	$s_{eff,1}$ + $s_{eff,n}$	43.9
		entire web is effective
	$s_{eff,1}$	0,4sn
	$s_{eff,n}$	0,6sn

***Table 3.2.2** – 2nd step values for the web*

The indentations are considered as plate elements with reduced thickness t_{red} = ρ x 0,71 for the length $L_{embossments}$ (Fig 1.3.2)

Determination of embossment ratio ρ

ρ = A*h + B, A and B are coefficients given in table 3.2.1

Type of local deformation	t (mm)	h (mm)	A	B
Indentation	0.71	0 - 1.5	-0.533	1.000
		1.5 - 2.75	-0.112	0.368
		2.75 - 4.0	-0.025	0.128
	0.96	0 - 1.5	-0.467	1.000
		1.5 - 2.75	-0.186	0.580
		2.75 - 4.0	-0.020	0.122
	1.21	0 - 1.5	-0.401	1.000
		1.5 - 2.75	-0.260	0.792
		2.75 - 4.0	-0.015	0.116
Embossment	0.71	0 - 1.5	-0.267	1.000
		1.5 - 2.75	-0.056	0.684
		2.75 - 4.0	-0.013	0.564
	0.96	0 - 1.5	-0.234	1.000
		1.5 - 2.75	-0.093	0.790
		2.75 - 4.0	-0.010	0.561
	1.21	0 - 1.5	-0.201	1.000
		1.5 - 2.75	-0.130	0.896
		2.75 - 4.0	-0.008	0.558

***Table 3.2.3** - Values of coefficients A and B*

For t=0.71 mm and h= 2,2 mm (1.5<h<2.75) ➔ A= - 0,112; B= 0.368

$\boxed{\rho\mathbf{=0,122}}$

Embossment reduced thickness t_{red} = 0,122 x 0,71= 0,087 mm for the length $L_{embossments}$ (Fig 1.3.2)

The cross section for calculation of the effective section is positioned to cause the most unfavorable effect. The calculation is performed in different cross sections, the section which induces the most important reduction of the resistance moment is the section which cuts symmetrically 2 embossments as in Fig. 3.2.1.

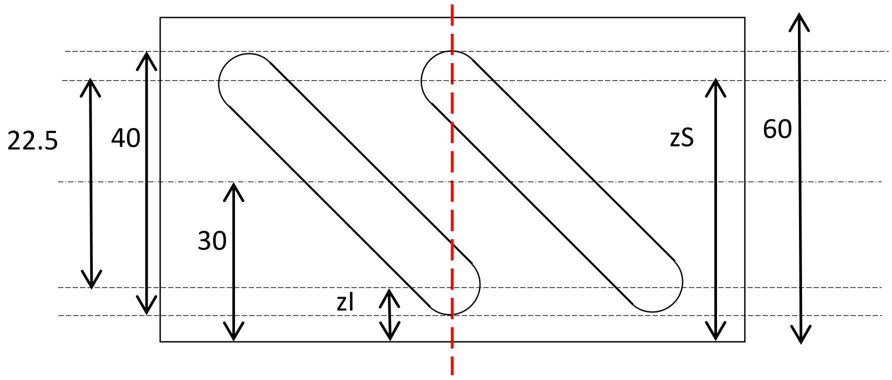


***Figure 3.2.1** - Section of the calculation*

zS = 60/2 + 22.5/2 = 41.25

zI = 60/2 -22.5/2 = 18.75

Lower flange effective area

Lower flange in this case is in tension ➔ Lower flange in this case is in tension ➔ all width is effective

Total effective area

Calculation of A_{eff}

Elément	l_i (mm)	t_{eff}	A_i(mm²)	z(mm)	S_i(mm³)	z0(mm)
1	8.50	0.27	2.3	60.0	140.1	-31.1
2	12.75	0.27	3.5	58.8	205.7	-29.8
Corner 1	0.00	0.27	0.0	57.5	0.0	-28.6
3	12.75	0.27	3.5	58.8	205.7	-29.8
41	10.00	0.27	2.7	60.0	164.8	-31.1
42	7.06	0.71	5.0	60.0	300.8	-31.1
Corner 2_{sup}	6.28	0.71	4.5	58.8	262.2	-29.9
5	55.82	0.71	39.6	30.0	1189.1	-1.1
Embossment S	-16.97	0.71	-12.0	41.3	-497.0	-12.3
	16.97	0.09	1.5	41.3	60.9	-12.3
Embossment I	-16.97	0.71	-12.0	18.8	-225.9	10.2
	16.97	0.09	1.5	18.8	27.7	10.2
Corner 2_{inf}	6.28	0.71	4.5	1.2	5.4	27.7
6	16.87	0.71	12.0	0.0	0.0	28.9
7	1.41	0.71	1.0	0.5	0.5	28.4
8	9.00	0.71	6.4	1.0	6.4	27.9
TOTAL			63.9		1846.4	28.9

Table 3.2.4 *- Elements lengths and areas*

A_{eff} = 63,9 mm²

Position of the neutral axis of the effective section: z_G = 28,9 mm

3.3. Iteration: Step3

All the values of step 3 are indicated in following table. The convergence is considered satisfactory at step 3, the iteration stops at step 3.

		3rd step
Upper flange	σ_{com}	320
	ρ pour b 2,eff	1
	0,5 b $_{2,eff}$	8.50
	ρ pour b 1,eff	1
	0,5 b $_{1,eff}$	10.00
Upper flange stiffener	$\sigma_{cr,s}$	102.7
	χ_d	0.37
	t_{red}	0.27
Web	e_c	31.1
	s_n	32.0
	$s_{eff,0}$	16.7
	$s_{eff,1}$	16.7
	$s_{eff,n}$	25.0
	$s_{eff,1}$ + $s_{eff,n}$	41.6
		entire web is effective
	$s_{eff,1}$	0,4sn
	$s_{eff,n}$	0,6sn
Total effective Area	A_{eff}	63.5
Position of neutral axis	z_c	28.7

***Table 3.3.1** – Step 3 values*

4. CALCULATION OF SPAN MOMENT RESISTANCE

The span moment resistance is calculated with step 3 data

Elément	l_i (mm)	t_{eff}	A_i(mm²)	z(mm)	S_i(mm^3)	z0(mm)	h	I_i(mm^4)
1	8,50	0,27	2,3	60,0	135,4	-31,3	0,7	2209,5
2	12,75	0,27	3,4	58,8	198,8	-30,0	2,5	3055,7
Corner 1	0,00	0,27	0,0	57,5	0,0	-28,8	0,0	0,0
3	12,75	0,27	3,4	58,8	198,8	-30,0	2,5	3055,7
41	10,00	0,27	2,7	60,0	159,3	-31,3	0,7	2599,4
42	7,06	0,71	5,0	60,0	300,8	-31,3	0,7	4908,6
Corner 2_{sup}	6,28	0,71	4,5	58,8	262,2	-30,1	0,0	4039,5
5	55,82	0,71	39,6	30,0	1189,1	-1,3	53,1	9375,7
Embossment S	-16,97	0,71	-12,0	41,3	-497,0	-12,5	16,1	-2156,2
	16,97	0,09	1,5	41,3	60,9	-12,5	16,1	264,0
Embossment I	-16,97	0,71	-12,0	18,8	-225,9	10,0	16,1	-1456,9
	16,97	0,09	1,5	18,8	27,7	10,0	16,1	178,4
Corner 2_{inf}	6,28	0,71	4,5	1,2	5,4	27,5	0,0	3377,1
6	16,87	0,71	12,0	0,0	0,0	28,7	0,7	9872,1
7	1,41	0,71	1,0	0,5	0,5	28,2	1,0	799,2
8	9,00	0,71	6,4	1,0	6,4	27,7	0,7	4906,9
TOTAL			63,5		1822,3	28,7		45028,6

***Table 4.1** – Step 3 data*

$M_{c,Rd} = W_{eff} \, f_{yb} / \gamma_{M0}$

For ½ pitch I_{eff} =45029 mm^4

For the profile I_{eff} = 435 mm^3

v = max (28,7;31,3)=31,3 mm

W_{eff} = I_{eff} / v = 13.9 mm^3

$\boxed{\mathbf{M_{span} = 4{,}4\ kNm/m}}$

5. CALCULATION OF END SUPPORT REACTION

Local transverse resistance of a web of a sheeting with longitudinal embossments (indentations) should be calculated according to the usual formula (6.18) of EN 1993-1-3

$$R_{w,Rd} = \alpha \, t^2 \sqrt{f_{yb} E} \left(1 - 0{,}1\sqrt{r/t}\right)\left[0{,}5 + \sqrt{0{,}02\, l_a / t}\right]\left(2{,}4 + (\phi/90)^2\right)/\gamma_{M1} \qquad (6.18)$$

In this case the reaction at end support is with $c \leq 1{,}5\ h_w$ clear from a free end therefore this is Category 1

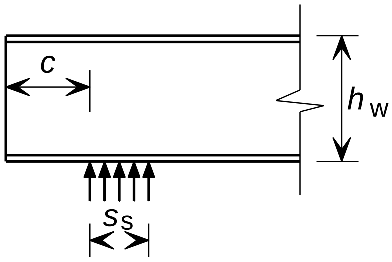


Figure 5.1 *- Reaction at end support with c ≤ 1,5 h_w : Category 1*

For Category 1 for sheeting profiles α = 0,075 and l_a = 10mm

t = 0,71 mm

r = 5 mm

ϕ = 72

Per web : $R_{w,Rd}$ = 713 N

Pitch = 207

Per meter: $\boxed{\mathbf{R_{w,Rd} = 6{,}9\ kN/m}}$

Annex 1

Background of the new design method for steel decks with embossments

D1.1	GRISPE WP1 Background document	Anna PALISSON (Sokol Palisson Consultants)
D1.2	GRISPE WP1 Test programme definition	Anna PALISSON (Sokol Palisson Consultants)
D1.3	GRISPE Test report of steel trapezoidal sheeting with and without em-bossments and outward stiffeners	Christian FAUTH (KIT)
D1.4	GRISPE WP1 Test analysis and interpretation	Anna PALISSON (Sokol Palisson Consultants)
D1.5	GRISPE Background guidance for EN 1993-1-3 to design of sheeting with embossments and indentations	Anna PALISSON (Sokol Palisson Consultants)